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THE SHIELDING EFFECTS OF VARIOUS MATERIALS WHEN INSECTS ARE EXPOSED TO THE LINES OF FORCE IN A HIGH FREQUENCY ELECTRO-STATIC FIELD[1]

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Introduction

It has been shown that electromagnetic waves can destroy certain insects when they are exposed in a high frequency electrostatic field: crickets (Lutz 1926); *Apis mellifera*, Glypta, *Musca domestica, Diabrotica 12-punctata, Pieris rapae,* and *Periplaneta germanica,* (Headlee and Burdette 1929). It appears that this destruction is due to the generation of internal heat of lethal degree (Headlee and Burdette 1929). It has also been found that there is a differential effect on plants and on insects: wheat seeds, seedlings, and *Apis mellifera* (Headlee 1931); bean seeds, and bean weevils (Hadjinicolaou 1931).

Insects live within and are surrounded by various common substances which the lines of force must penetrate if they are to

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kill the insects. For this reason a study of the shielding effects of these common substances was undertaken. The common substances within which insects work and by which they might be protected are: liquids, solutions, oils, chemical elements, soil minerals, soils, carbohydrates and proteins.

THE APPARATUS

The machine used was a vacuum tube oscillator. The active field was formed by two 6″ x 6″ aluminum plates facing each other. When an alternating E.M.F. is set up across the plates the dielectric is strained first in one direction and then in the other. These stresses that are set up are equivalent to displacement currents in the dielectric. The experimental subjects were placed between the plates so that they were in the direct path of the lines of force.

A constant frequency of 3,000,000 cycles per second and a constant field strength of 2,620 volts per linear inch were maintained except where otherwise specified.

EXPERIMENTAL PROCEDURE AND RESULTS

In the investigations two pyrex glass tubes were used: one, 100 mm. long and 13 mm. in diameter; the other 150 mm. long and 25 mm. in diameter. The smaller tube containing three adult worker honey bees, which were the insects used in the investigations, were placed in the larger one and the material to be tested was then placed in the larger tube around the smaller tube. This left a wall of 6 mm. of substance all around the bees. In this way the penetrating effect of the lines of force could be studied, and at the same time the heating effects on the substances were also investigated.

The lethal effect of the lines of force to the worker honey bee was first determined when the bees were shielded by the air between the inner and the outer tubes. The time to kill the bees under this condition was used as the standard of comparison with the time to kill them when other substances were used. This time was found to be, as an average of 20 trials, 4 minutes and 13 seconds and was given the unit value of one. All other time observations were divided by this time to kill so that a series of time index numbers were obtained with the lethal effect through

TABLE 1
PENETRATING AND HEATING OF LIQUIDS

Liquid	Condition	No. of Runs	Temperature Rise °F.		Time Index Air = 1	Dielectric Constant	Condition of Bees
			Inner Tube	Substance			
Water	Distilled	7	3°	3.3°	2.37	81	Normal
Water	Triple Distilled	3	5.2°	2°	2.37	81	Slightly excited
Glycerine	U. S. P.	3	4°	.5°	2.37	45	" "
Methyl Alcohol	Crude	3	40.6°	44.6°	2.37	40	Dead (from outer heat)
Ethyl Alcohol	95%	3	10°	5°	2.37	30	Weakened
Amyl Alcohol	U. S. P.	3	40.6°	46°	.99	15	Dead (from outer heat)
Analine	Pure	3	15°	6.6°	2.37	7.2	Very weak
Chloroform	U. S. P. Ak. 1%	7		1°	1.42	5	Dead
Petrolatum	Extra Heavy	5		3°	1.04	2.2	"
Petroleum Oil	Light	5		2.2°	.97	2	"

air as a standard of comparison. The time index is never over 2.37, since the lines of force produced no lethal effect on the honey bees, if they did not kill them in ten minutes.

Penetration Through Liquids. A series of liquids were taken (table 1) whose dielectric constants, according to the International Critical Tables, ranged from 81 to 2. An examination of the table shows that there is a definite relation between the dielectric constant of the liquids and the lethal effect of the lines

TABLE 2

PENETRATION AND HEATING OF AQUEOUS SOLUTIONS

Solution	Condition	No. of Runs	Temperature Rise °F. Inner Tube	Temperature Rise °F. Substance	Time Index Air = 1	Condition of Bees
Non-Electrolytes						
Dextrose	$\frac{M}{10}$	3	4°	3°	2.37	Excited
Sucrose	$\frac{M}{10}$	3	4°	4°	2.37	"
"	$\frac{M}{2}$	4	4°	3°	2.37	"
Wheat starch	$\frac{1 \text{ gm.}}{100 \text{ cc.}}$ Colloidal	3	6.3°	6°	2.37	"
Blood Albumin	$\frac{1 \text{ gm.}}{100 \text{ cc.}}$ Soluble	2	3°	1°	2.37	"
Egg Albumin	$\frac{1 \text{ gm.}}{100 \text{ cc.}}$ Soluble	2	3°	2°	2.37	"
Electrolytes						
KCl	$\frac{M}{10}$ Highly ionized	7	1.3°	1.3°	2.37	Normal
NaCl	$\frac{M}{10}$ Highly ionized	7	1.6°	1.6°	2.37	"
$MgSo_4$	$\frac{M}{10}$	6	2°	2°	2.37	"
KH_2Po_4	$\frac{M}{10}$	5	1.6°	1.6°	2.37	"
Sodium silicate	$\frac{M}{10}$	5	1.8°	1.8°	2.37	"
$Fe(OH)_3$	$\frac{M}{10}$ Colloidal	5	10.2°	10.2°	2.37	Slightly excited (from outer heat).

of force: namely that the lethal effects of the lines of force increase with decreasing dielectric constants.

Penetration Through Aqueous Solutions. An investigation of table 2 brings out the fact that there is apparently no penetration of the lines of force through electrolytic solutions while through non-electrolytic solutions there is apparently enough to excite the bees. Evidently the conducting solutions deflect the lines of force. The table also shows a tendency for heating to be less in electrolytic solutions. The two colloidal substances used caused higher heating of the solutions. Marshall (1930) states that the rapid heating of a carbon disulfide emulsion is due to its colloidal structure, but gives no further explanation for the cause of rapid heating.

The Penetration Through Oils. A study of the lethal effect of the lines of force through oils (table 3) shows that there is greater lethal effect through mineral oils than through either animal or plant oils. Of the animal oils, the lethal effect through cod-liver oil was the quickest; and of the plant oils, the lethal effect through pine oil was the quickest. None of the oils showed any marked heating effects.

TABLE 3

PENETRATION THROUGH AND THE HEATING OF OILS

Oil	Condition	No. of Runs	Temperature Rise °F.		Time Index Air = 1	Condition of Bees
			Inner Tube	Substance		
Petroleum	Light	5		2.2°	.97	Dead
"	Heavy	5		1.4°	1.06	"
Petralatum	Extra heavy	5		3°	1.04	"
"	Light	5			1.18	"
Cod-Liver	Pure	5		2.4°	1.27	Dead
Whale		6		5°	2.37	Very weak and dead
Pine	Light	5		4°	1.27	Dead
Cedarwood		5		8.4°	1.90	"
Bergamot		2	14°	9°	2.37	Weakened
Linseed	Raw	5	12°	7.5°	2.37	"
Cinnamon		3	8.3°	4.3°	2.37	"
Citronella	Java	3	6°	4.3°	2.37	"

The Penetration Through Chemical Elements. An examination of certain elements (table 4) shows that lead foil from cigarette packages, copper wire screening; tin sheeting; iron wire screening; silver, precipitated on inside of large test-tube; and mercury are all perfect shields to the insects. The size of the mesh in the screening did not appear to affect the deflection of the lines of force. On the other hand, metals in the form of aluminum dust, zinc dust, granular manganese, and granular nickel allowed the penetration of the lines of force to a varying degree. Evidently the surfaces of the particles had become oxidized, causing the metals to act as dielectrics. Of the two non-metallic elements carbon, a conductor, was a shield and sulfur, a non-conductor, facilitated the passage of the lines of force into the inner tube. Very little heating was observed in the metals with the exception of granular nickel which showed rapid treating under the effect of the stresses.

TABLE 4

THE PENETRATION THROUGH AND THE HEATING OF METALLIC AND NON-METALLIC ELEMENTS

Substance	Condition	No. of Runs	Temperature Rise °F. Inner Tube	Temperature Rise °F. Substance	Index Time Air = 1	Condition of Bees
Silver	Pure sheet	5			2.37	Normal
Copper	Wire screening	5			2.37	"
Iron	Wire screening	5			2.37	"
Tin	Sheeting	5			2.37	"
Lead	Foil	5			2.37	"
Mercury	Liquid	3			2.37	"
Aluminum	Dust	3	10.3°	3.3°	2.37	Excited
Nickel	Granular	4		30.5°	2.30	Dead
Manganese	"	12		2°	1.47	"
Zinc	Dust	8		5°	1.04	"
Carbon	Conductor Dust	5	7.4°	7.6°	2.37	Normal
Sulfur	Non-Conductor Dust	5		3.6°	.84	Dead

Penetration Through Soil Minerals. The small time indexes indicate a rapid lethal effect through all of the soil minerals examined (table 5). In none of the soil minerals was there a lethal heat accumulated to cause the death of the bees, except in the case of tri-calcium phosphate where the temperature rose 38.5 degrees F. in one minute and 22 seconds in the dry material.

TABLE 5

THE PENETRATION THROUGH AND THE HEATING OF SOIL MINERALS

Substance	Condition	No. of Runs	Temperature Rise °F. Inner Tube	Temperature Rise °F. Substance	Time Index Air = 1	Condition of Bees
Silica	Ground	5		5=	.77	Dead
Iron Hydroxide	Colloidal	5		21.4°	.80	"
Gypsum	$CaSO_4 \cdot 2H_2O$	5		5.4°	.71	"
Calcite	$CaCO_3$	5		9.3°	.63	"
Kaolin	$H_2Al_2(SiO_4)_2 \cdot H_2O$	5		19°	.53	"
Magnesium Oxide	MgO	5		20°	.53	"
Calcium Phosphate	$Ca_3(PO_4)_2$	6		38.5°	.35	"

Penetration Through Soils. Examination of table 6 shows that soils greatly facilitate the penetration of the lines of force and that moisture content of the soils is of great importance in the lethal effect of these lines of force. It appears that clay even in the dry condition heats rather rapidly. Small amounts of moisture which are insufficient to raise the temperature of the soils high enough to kill the bees appear to hasten the lethal effect of the stresses. The speed of kill and also the heating increases with the amount of water added to a certain point, and then diminishes with the addition of more water. The table also brings out the abnormal heating of water when it is in a dispersed state. According to Hosmer (1928) rate of heating is directly proportional to the length of the conducting path measured perpendicular to the plates and inversely proportional to its cross-section. Since dispersing the water increases the length of the conducting path in proportion to its cross-section, dispersed water is heated rapidly. To investigate the effect of dispersed liquids on heating, water and oil were exposed to the lines of force in mass, and then a foam emulsion, made of a very small quantity of albumin solution mixed and shaken with oil, was exposed to the lines of force. The latter form heated more than ten times as fast, rising 80 degrees F. in ten minutes. Another test was run wherein the water was dispersed by means of glass beads. The distilled water without the beads was heated 5° F. in 10 minutes, while the same volume of water dispersed by the glass beads was heated 18° F. in the same length of time. It is apparent that dispersed water in soils and similar substances is a major factor in the speed of heating of these substances.

Of the soils used and with the water content employed humus appears to have the ability to hold the greatest per cent. of moisture by weight with the least heating effect. A mixture of equal parts by weight of sand, clay, and humus may hold 10 per cent. moisture by weight or even more, without approaching a lethal temperature before the bees are killed by the lines of force.

TABLE 6

A STUDY OF THE SHIELDING AND HEATING EFFECTS OF SOIL

Substance	Condition	No. of Runs	Temperature Rise °F.		Time Index Air = 1	Condition of Bees
			Inner Tube	Substance		
Clay	Oven Dry Ground	5		20°	.66	Dead
"	5% H_2O by wt.	5		35°	.64	"
"	20% H_2O by wt.	5	18.4°	12.8°	2.37	Weakened
Humus (Peat)	Oven Dry Ground	5		6°	.70	Dead
"	5% H_2O by wt.	6		6.6°	.63	"
"	20% H_2O by wt.	5		34.6°	.43	"
Sand	Oven Dry Fine	5		2°	.72	"
"	5% H_2O by wt.	5		43°	.48	"
Clay, Sand, Humus	Oven Dry Ground	5		2.4°	.54	"
Clay, Sand, Humus	5% H_2O by wt.	5		12.6°	.52	"
Clay, Sand, Humus	20% H_2O by wt.	5		39.8°	.38	"

Penetration Through Carbohydrates. Examination of table 7 shows that compared to air the lethal effect of the lines of force is on the whole greater through carbohydrates in the solid form. Different types of woody materials are easily penetrated by the lines of force. Addition of moisture to the wood frass accelerated the speed of kill of the bees as in the case of soils.

The pipe tobacco and the breakfast foods heat somewhat, but the lines of force proved lethal to the bees before the outer heat was great enough to kill the bees. An external temperature of about 118° F. is necessary to kill the bees. Hard wax has a time index very near that of air; and both dry raisins and green leaves protect the bees from the lines of force. They also heat readily because of moisture in them.

TABLE 7

A STUDY OF THE SHIELDING AND HEATING OF CARBOHYDRATE COMPOUNDS

Substance	Condition	No. of Runs	Temperature Rise °F.		Time Index Air = 1	Condition of Bees
			Inner Tube	Substance		
Paper	Corrugated	10			.58	Dead
"	Manila	10			.80	"
Cloth	Cheese	10			.81	"
Cellophane		10			.86	"
Paper	Waxed	10			.95	"
Cedar wood	Dry Frass	6			.96	"
" "	5% H_2O by wt.	5		8°	.92	"
" "	10% " " "	3		29°	.50	"
" "	Bark	10			.96	"
Excelsoir	Cut up	5			.96	"
Soft wood	Xylem	5			.98	"
Tobacco	Pipe	3		13°	.62	"
Wheat	Grain	10			.72	"
Quaker Oats	Ground	3		9°	.80	"
Rice Krispies	Ground	3		7°	.76	"
Sucrose	Dry granulated	5		2°	.90	"
Starch (Wheat)	Dry colloidal	5		6°	.93	"
Dextrose	Dry powder	5		4°	1.30	"
Raisins	Dry	1		36°	2.37	Dead (outer outer heat)
Green leaf		1		31°	2.37	Excited (by outer heat)
Paraffin	Wax solid	6		1°	1.02	Dead

Penetration Through Protein Materials. Examination of table 8 also shows accelerated lethal effects with protein substances. Chitin and the albumins show some heat accumulation, but not rapid enough to cause the death of the bees.

Penetration Through Vacua. Since the atmosphere is the basic dielectric involved in the lethal effects of the lines of force, a study was made of their lethal effect to the honey bees through

TABLE 8

A STUDY OF THE SHIELDING AND HEATING EFFECTS OF PROTEINACEOUS SUBSTANCES

Substances	Condition	No. of Runs	Temperature Rise °F.		Time Index Air = 1	Condition of Bees
			Inner Tube	Substance		
Leather	Chamois	5			.77	Dead
Albumin	Crystalline Dry Blood	3		16°	.72	"
"	Powder Dry Egg	3		13°	.78	"
Chitin	Flakes	3		12°	.80	"
Wool	Cloth	5			.84	"

different degrees of vacuum (table 9). In every case there is an abnormal rise in the time to kill from normal conditions to the first 5 inches of vacuum; after that there appears to be a gradual increase in time to kill to the highest degree of vacuum. It was observed that it took more time to kill the bees the first one or

TABLE 9

THE LETHAL EFFECT OF LINE OF FORCE THROUGH DIFFERENT DEGREES OF VACUUM

Degree of Vacuum	Field Strength	No. of Runs	Time in Minutes and Seconds	Condition of Bees
Normal	2,620	5	3′: 57″	Dead
5″	"	3	10′: 00″	Normal
10″	"	1	10′: 00″	"
25″	"	1	10′: 00″	"
5″	3,275	3	5′: 30″	Dead
10″	"	3	5′: 47″	"
15″	"	3	6′: 5″	"
20″	"	5	6′: 39″	"
25″	"	4	7′: 30″	"
30″	"	5	7′: 39″	"
Normal	3,930	5	0′: 26″	"
5″	"	5	2′: 7″	"
10″	"	5	2′: 17″	"
15″	"	5	2′: 18″	"
20″	"	5	2′: 17″	"
25″	"	4	2′: 46″	"
30″	"	5	2′: 58″	"

two trials with each new tube than in the following trials. No lethal effect whatsoever could be obtained at the field strength used in the preceding investigations with the vacuum tubes, therefore, it was found necessary to increase the field strength to 3,275 volts per inch until lethal effects were observed.

General Discussion. From these investigations it appears that the dielectric constant of liquids plays a major part in the lethal effect of the lines of force, which grows smaller as the dielectric constant increases. It does not influence the lethal effect in solid dielectrics, since the dielectric constant is small in most of them. Water containing ionized solutes and solid conductors appears to have a complete shielding effect on the honey bees, but there is some penetration of the lines of force through conductors in granular or dust state with oxidized surfaces. The lethal effect of the lines of force is greatly increased through soil minerals, soils, carbohydrates, and proteins. When moisture is added the lethal effect through soils and heat production in soils and similar materials increases with a rise in moisture content to a certain point and decreases with greater amounts beyond that point. The lethal effect of lines of force through vacua decreases with increasing evacuation to near 30 inches of mercury.

The investigations also show that colloidal solutions were heated more than ionic or molecular solutions; that tricalcium phosphate has an abnormal rate of heating; that heating is negligible in most dry solid dielectrics; and that the heating of soils and similar substances depends upon the degree of dispersion of the water and the quantity of water in them.

Conclusions. The lethal effect of lines of force in a high frequency electro-static field is limited in solid dielectrics mostly by moisture content; and in pure liquids by the dielectric constant.

Electrical conducting substances whether liquid or solid act as shields to insects when they are exposed to the lines of force between the plates.

As a result of these investigations it is considered possible to destroy insects in many substances without injuring them with excessive heat. These substances are mainly: soils with a limited amount of moisture, woody materials, tobacco, grains or seeds, breakfast foods, clothes, flours, paper, cellulose compounds, and nuts.

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